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Low-carbon innovation and technology transfer in latecomer countries: Insights from solar PV in the clean development mechanism



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ABSTRACT

This paper examines the organizational arrangements for technology supply in solar photovoltaic projects in the Clean Development Mechanism (CDM). It shows that while lower middle-income countries typically import solar PV equipment into CDM projects, China, India and Thailand have begun to use new organizational arrangements for technology transfer which reflect the overall industry maturity in the solar PV sectors in these countries. This has great potential for long-term climate change mitigation efforts. However, the initiation of these new organizational arrangements often preceded the supply of technology into CDM projects. This raises important questions about the role of CDM in spearheading the development of technological capabilities required for sustainable development. The paper uses these findings to add to the literature about technology in CDM and to the wider policy debates over the future of the global climate regime. Technology transfer does not become less important as developing countries' capabilities mature, but the nature of technology transfer changes over time. This suggests a need to differentiate between countries at different levels of development. Lower middle-income countries may have greater needs for building technological capabilities whereas cooperative activities may be suitable for upper middle-income countries that already have capabilities to address climate change.

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1. Introduction

The global community is currently discussing how new policies, instruments and funds can aid the global response to climate change in a 'Climate Regime Mark II' by 2020 as a replacement of the current Kyoto Protocol (or 'Climate Regime Mark I'). Understanding the role of technology transfer matters in this regard because there is strong recognition that policy debates need a deeper understanding of the arrangements through which technology is developed and deployed internationally (Berkhout et al., 2010; Ockwell et al., 2008).¹ This article seeks to inform those policy debates by seeking insights from technology transfer in the Clean Development Mechanism (CDM). The CDM is a 'project-based' mechanism under the Kyoto Protocol devised to encourage production of emission reductions in developing countries. To stimulate sustainable development, CDM should facilitate low-carbon technology transfer from advanced to developing economies in connection with implementation of emission reduction projects (UNFCCC, 2002). Depending on how technology is supplied and deployed, CDM projects may stimulate technological

learning and related upgrading of capabilities to mitigate climate change both within and potentially beyond the individual CDM project. In other words, understanding the technological learning results of CDM projects is important to assess the dynamic opportunities for virtuous cycles of mitigation capabilities, technology cost reductions and further greenhouse gas reductions. Insight on these issues could further help to understand how opportunities diverge between lower middle income countries and emerging economies that have very different preconditions for engaging with advanced technology as well as different capabilities for contributing to mitigation of climate change.

1.1. Technology and sustainable development in CDM

The Clean Development Mechanism was established with the 1997 Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC) and is currently in effect as an element of the second commitment period from 2013 to 2020. The CDM was established with a double objective. First, it created a mechanism whereby developed countries could comply with their national greenhouse gas reduction commitments by implementing emissions reduction projects in developing countries. CDM provides a financial incentive – through generation of tradable certified emissions reductions – to implement low-carbon projects in developing countries. Secondly, it sought to promote sustainable development in low and middle income CDM project 'host countries'. Although developing countries do

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¹ The term 'policy debates' is used in a broad sense, including negotiations in the United Nations Framework Convention on Climate Change (UNFCCC) over reform of CDM and the future of mitigation action as a whole, and the political and academic debates regarding technological capabilities and capacities for mitigation actions by emerging economies such as China and India.

not have emissions reductions commitments, the CDM has to assist these countries in achieving a low-carbon development pathway.

However, the results of the twin objective of CDM are much debated. First, while CDM is increasing the costs effectiveness of developed countries' Kyoto Protocol compliance, there is some controversy because it is questioned whether some CDM projects are additional to baseline emissions scenarios. Some CDM projects are already so cost-effective that they would have been implemented without the CDM revenue stream (Schneider, 2009). Secondly, there is a debate over whether CDM has been more effective in reducing mitigation costs than in advancing sustainable development (World Bank, 2010; Castle, 2012). Several studies show that so-called 'co-benefits' associated with CDM, such as job creation or improved air quality, are often absent or rather limited (Nussbaumer, 2009; Olsen and Fenhann, 2008; Sutter and Parreño, 2007).

The same discussion is ongoing about one particular co-benefit: transfer and development of technology (UNFCCC, 2012). The guidelines for CDM stipulates that 'clean development mechanism project activities should lead to the transfer of environmentally safe and sound technology and know-how' (UNFCCC, 2002). Before approval, CDM project design documents have to include a description of 'how technology will be transferred, if any'. Hence, technology transfer is a potential by-product of CDM projects, not a formal obligation. There is agreement, however, that technology transfer in CDM projects can help developing countries to address the climate mitigation challenge.

1.2. Research focus

A substantial body of literature has addressed the extent of technology transfer in CDM projects (e.g. de Coninck et al., 2007; Dechezleprêtre et al., 2009; Dechezleprêtre et al., 2008; Haščić and Johnstone, 2011; TERI, 2012; UNFCCC, 2010, 2012). Much of this research is consistent with the technology transfer definition by the Intergovernmental Panel on Climate Change, that technology transfer comprises a "broad set of processes covering the flows of know-how, experience, and equipment" between various types of actors (IPCC, 2000, p. 3).² Effectively, however, much CDM research has focused on a subset of the definition: import of mitigation equipment into developing countries. Flows of equipment (and associated know-how) deliver primarily mitigation capacity to technology importing countries, which is the main purpose of CDM. But alone they add little to these countries' innovation capacity or technological learning (Bell, 1990, 2009). In other words, most technology transfer in CDM literature shed little light on actual organizational arrangements for technology transfer and the impact of technological learning and innovation.

To do so, it is necessary to search beyond simply import of equipment and assess the full a variety of organizational arrangements underlying CDM projects. It is not sufficient to only distinguish between local and foreign technology. This insight comes from recent studies which showed that technology used in CDM projects does not just come from cross-border trade in off-the-shelf products. It is also delivered through organizational arrangements such as subsidiaries of multinational enterprises, joint ventures or licensing of technology (Hansen, 2011). These organizational arrangements for technology transfer have been described as 'conventional' in that technology flows more or less unidirectional from developed to developing countries and that they require little interaction and effort by recipients.³ Recent non-CDM literature has further identified 'unconventional' transfer which involve even more complex processes of technology transfer, implying that flows are not unidirectional and

that collaborative interaction and developing country effort are high (Lema and Lema, 2012; Fu and Zhang, 2011).

This study extends the CDM technology transfer literature by examining conventional and unconventional transfer and local innovation through what we term 'organizational arrangements' for local and international technology supply in CDM. We examine whether, how and ultimately why firm-level organizational arrangements differ between countries hosting CDM projects. This study is empirically based on research of solar photovoltaic (PV) technology in CDM projects. Solar PV is a useful sector for examining organizational arrangements for technological learning in CDM because it is implemented in different types of developing countries and solar PV is likely to become an important source of low-carbon electricity in developing countries. It is pertinent to examine this because the bulk of solar PV CDM is located in relatively advanced emerging economies. Given that some emerging economies have solar PV industries, it is relevant to examine the role of the CDM in opening up new organizational arrangements at the country level.

The paper is guided by the following research questions: What are the key organizational arrangements in solar PV CDM projects? Are there differences between CDM solar host countries with respect to the degree to which they utilize different types of organizational arrangements? To what extent do CDM projects spearhead new arrangements that have not previously been utilized in host countries?

To answer these questions, the paper is structured as follows. The next section develops the analytical framework for analysis. It draws on the literatures on technological capabilities and international technology transfer. Section 3 describes our methodology which uses 'observed' organizational arrangements as the basis of analysis. In contrast to the previous methodological paradigm that used CDM internal data (projects 'claims') (e.g. de Coninck et al., 2007; Dechezleprêtre et al., 2008; Seres et al., 2009; UNFCCC, 2012) we also draw significantly on CDM external data and contextual information. Section 4 presents the empirical findings describing the organizational arrangements and their distribution between countries. Case studies of China, India and Thailand are analyzed due to their simultaneous importance in solar PV CDM projects and their "latecomer" status.⁴ This section also examines whether CDM appears to instigate new organizational arrangements or not. Section 5 concludes the paper and discusses the implications for policy makers and scholars interested in climate and energy related to technology transfer and innovation in developing countries.

2. Low-carbon innovation and technology transfer in latecomer countries

This section develops a framework for examining organizational arrangements used in the CDM. In order to do so we begin with the role of technological development in latecomer settings and subsequently we explore the role of international linkages in this respect. Finally, we present a typology of local innovation and conventional and unconventional transfer that may be used for delivery of technology into CDM projects.

2.1. Sustainable development, learning and innovation in latecomer settings

The accumulation of relevant technological and innovation capabilities adds to countries' ability to engage in climate change mitigation, not only as a user of low carbon technology but also as a producer and innovator (Bell, 2012; Ockwell et al., 2013). Merely importing and installing solar panels or other green technologies

² For a discussion and critique of the term, see Lema and Lema (2012, p. 39f).

³ Such mechanisms are also important for the transfer of low carbon technology outside the CDM (e.g. Brewer, 2008; Less and McMillan, 2005; Popp et al., 2011).

⁴ South Korea is not included as a case country. Although South Korea is a non-Annex 1 (developing) country in the UNFCCC and a considerable host to solar PV projects, it is also an OECD country and we do not give it particular attention.

may constitute “a quick fix” that may add little to the local learning process. Engaging creatively with the underlying technology contributes more to a country's ability to master and tailor the relevant processes involved in sustainable development. Furthermore, local involvement in the technology development process may enable a commitment to sustainable development because it allows developing countries to reap the associated co-benefits such as employment and export opportunities (UNCTAD, 2010).

Building on these insights, this study draws on the literature on technological learning and innovation in developing countries (such as Bell, 1990; Ernst and Kim, 2002; Lall, 1993). This literature has shown that there is rarely a clear boundary between ‘innovation’ and ‘diffusion’ because the latter is often a creative process involving adaptation and further development of imported technology. It has pointed out limitations to the notion that diffusion is merely a matter of picking technology from the shelf and adopting it in the host economy without the need to make further investments in learning (Bell, 2009; Bell and Pavitt, 1993; Doranova et al., 2010). The level of the recipients' own investment in capabilities is essential to accumulate technological capabilities (Lall, 1993; Reddy and Zhao, 1990). Recipient efforts are required for the capacity to absorb technology obtained from external sources (Cohen and Levinthal, 1990) and for engaging creatively to improve it and apply it in new projects (Bell, 2009). In other words, technology transfer and local innovation are largely complementary (Fu et al., 2011; Lall, 1993). At the firm-level, technological learning is likely to involve a sequence of activities that combine firm-internal generation of skills and capabilities with outside knowledge which requires significant investments in knowledge, experimentation and organizational routines (Bell, 2009; Ernst and Kim, 2002; Lall, 1993).

Since the notion of technological ‘diffusion’ sometimes refers primarily to flows of ‘hardware’ or paper-embodied technology based on simple market transactions (Less and McMillan, 2005; Ueno, 2009; World Bank, 2008), the transfer requirement is therefore a relatively ‘thin’ unidirectional flow from technology supplier to importer, with relatively low levels of cross-border interaction. However, tacit knowledge is difficult to transfer. This typically requires high intensity interaction between user and producer of relative long duration which facilitates local firms' active involvement and ‘conversion’ of relevant knowledge (Ernst and Kim, 2002; Lundvall, 2011). Deeper levels of cross-border interaction may lead to more learning opportunities in the transfer process. People-embodied knowledge – as opposed to knowledge embodied in machinery – is crucial, not only for operating installed technology, but also for managing technical change. Given the important intangible dimensions of technology transfer, importing physical artifacts alone without the human skills to engage creatively with them provide only relatively shallow learning opportunities and do not help countries or firms onto self-reinforcing sustainable development paths.

Effective ‘transfer’ of technology requires an understanding of the knowledge, designs and production systems enabling modifications and further innovation by recipients (Ockwell et al., 2008, p. 4106; UNCTC, 1987, p. 1). Such ‘further innovation’ requires not only know-how but also know-why, the ‘deeper’ system specific knowledge required for managing technical change. Apart from relying on international learning, firms can build capabilities through local ‘in-house’ technological development through experimental efforts to adapt and modify technology and through interaction with other actors in the national systems of learning, innovation and competence building (Lundvall, 2011).

This learning perspective on technology development in latecomer countries departs from a more narrow view inspired by conventional economics which sometimes suggests that innovation in developing countries tends to be costly and of low quality compared

to technology from advanced economies. Local investment in learning and innovation is therefore sometimes seen as an inferior alternative to technology transfer. This view follows an assumption of ‘non-innovativeness’ in developing countries. Much classical research on the subject tended to focus on “non-creative industrial technological activity in developing countries” (Bell and Figueiredo, 2012, 14). But a substantial body of literature has subsequently refuted the ‘non-innovation’ assumption and shifted the emphasis to questions about the depth, speed and organizational arrangements for technical learning and innovation. This study is concerned mainly with the organizational arrangements and particularly with the changing nature of global linkages in this regard.

2.2. Local innovation, conventional and unconventional technology transfer

In this study we adopt three main categories to examine the organizational arrangements: (i) Local innovation, (ii) conventional technology transfer and (iii) unconventional technology transfer (Lema and Lema, 2012).

2.2.1. Local innovation

The type of firm that until recently was viewed as more or less unimportant for the global economy is the ‘indigenous technology provider’ which is a latecomer firm using own innovations to produce in the home economy for exports or local sales. Such firms have little interaction with foreign technology sources – at least for the specific technology in question. On the other hand, local innovators have invested considerable efforts and resources to develop the technology and produce the technology.

2.2.2. Conventional technology transfer

Trade has in mainstream economics been the classical vehicle of technology transfer, and later FDI and wholly owned subsidiaries was identified as a substitute for trade under certain conditions (Dunning, 1981; Grossman and Helpman, 1995; Jian-Ye, 1990; Krugman, 1979; Romer, 1994). The variety of conventional organizational arrangements for international technology and production has now been identified in the literature to include trade in hardware, foreign investments, joint ventures and technology licensing (Hoekman et al., 2005). Conventional technology transfer is characterized by limited cross-border interaction and recipient effort.

2.2.3. Unconventional technology transfer

Enabled by the increasing global distribution of innovation activities and global reorganization of firm networks (Altenburg et al., 2008), developing country firms are beginning to acquire technology from foreign sources such own overseas R&D, strategic alliances and foreign acquisitions and collaborative R&D with foreign organizations. Such unconventional transfer require substantial interaction and human or capital investments by the ‘recipient’. For example, it requires absorptive capacity to internalize knowledge embodied in people and organizational routines in an acquired firm (Rui and Yip, 2008), and it requires own innovation skills to undertake R&D alone or cooperatively in foreign locations. While these organizational arrangements are difficult and costly, the literature on technological learning suggests they may be promising for creation of new technology and catching-up (Bell and Figueiredo, 2012). They have been particularly important in ‘national champion firms’ in emerging economies (Altenburg et al., 2008; Fu et al., 2011). There is some evidence that unconventional transfer usually is adopted only after a period of either local technology development or conventional technology transfer.

2.3. Organizational arrangements for technology transfer and local innovation: variables and categories

We define organizational arrangements as the practical ways to develop or transfer technology. We adopt an analytical approach that defines conceptual organizational arrangements along four variables⁵:

- (i) Location of equipment production refers to whether the manufacturing of physical equipment takes place within the country of use or in an exporting country. The location of production of technological equipment is important for deeper technology flows because setting up of production facilities is likely to enhance the quality of interaction between technology provider and importer, regardless of the nature of technology ownership.
- (ii) Ownership of equipment manufacturer refers to whether the technology-producing firm has majority ownership within or outside a developing country. This dimension is important because multinational firms may 'transfer the results of R&D, rather than the innovation process itself' (Lall, 1993, p. 103).
- (iii) Origin of proprietary technology refers to the geographical locus of the core innovation process, i.e. whether the key technological knowledge is mainly produced within the developing country or whether that development has taken place in foreign countries.
- (iv) Ownership of proprietary technology refers to whether the technology is owned by the firm which sells the technology in the local market (i.e. supplies the CDM project). Technology is often owned external to the manufacturer when two or more organizations are cooperating such as in license agreements, joint ventures, and in joint R&D projects. In this case, the developing country manufacturer is relying on technology which is owned by another firm or organization.

Fig. 1 provides an overview of organizational arrangements and how they relate to technology flows and impact.⁶ The next section explains how these variables have been used to classify organizational arrangements observed in solar CDM projects.

3. Methodology

This section provides the methodology underlying the study of low-carbon innovation and technology transfer in latecomer countries. This is based on research on solar PV technology in CDM. The choice of solar PV is useful for several reasons. First, solar PV CDM is implemented in several different countries which enables an assessment of the differences between low and middle income countries and emerging economies. Secondly, solar PV is a fairly coherent technology complex which makes it practically feasible as a case compared for instance to energy efficiency which comprises several sub-technologies and processes. Third, previous non-CDM studies have shown that both conventional and unconventional organizational arrangements are used at least in emerging economies. Finally, while solar PV is not the only useful option for such research, solar PV in CDM has not previously been researched as an individual case which allows for completely new knowledge in

CDM technology transfer research. Wind power, for instance, which shares the characteristics above, is well researched elsewhere (Haščič and Johnstone, 2011; Lema and Lema, 2013).

This section goes on to provide a review of the earlier methodological 'paradigm' in CDM technology studies and uses this as a platform to describe the methodology used in this study.

3.1. Methods in prior literature on technology transfer in CDM

Much earlier CDM technology research has focused on the extent to which CDM has transferred technology or not. The methodologies have with few exceptions been strikingly similar using data from key word searches for project design documents' claims or statements relating to transfer of technology or the stated origin of used equipment (Das, 2011; de Coninck et al., 2007; Dechezlepretre et al., 2009; Dechezlepretre et al., 2008; Doranova et al., 2010; Haïtes et al., 2006; Seres et al., 2009; UNFCCC, 2010, 2012; Youngman et al., 2007). This research arrives at the conclusion that about one third or two fifths of project documents indicate transfer. As a starting point, this study also tabulated and analyzed the claims and indications made by projects participants in project documents in a sample of the first 61 registered solar PV CDM projects. The purpose was to compare this well-known methodology with our methodological development as explained in Section 3.2. Using the 'claims method' we arrive at a similar conclusion for solar PV CDM projects which shows that 38% of projects claim technology transfer, and a quarter claim that the technology is local (Table 1).

However, the claims method is neither entirely accurate nor sufficiently detailed for our purposes. First, as we shall see later, our method and data provides insights beyond the data in Table 1. For obvious reasons, the binary claims methodology is not sufficient when seeking insight along the lines of the pluralistic analytical framework as presented earlier. Secondly, the challenge with the claims method is that it relies on ambiguous statements by project participant with very different definitions of technology transfer (if any). Some studies provide econometric analysis to explain technology transfer claims or other similar indications (Dechezlepretre et al., 2009; Dechezlepretre et al., 2008; Doranova et al., 2010). While these provide valuable insights they too do not provide details of used organizational arrangements. Moreover, the problem is also that their dependent variable (e.g. 'transfer' or 'local technology') may not be entirely accurate if project participants' definitions of transfer run contrary to scholarly frameworks.

3.2. Methodology of this study

Departing from claims in project documents to assess in detail how organizational arrangements – conventional, unconventional and local innovation – have been used in CDM projects requires a method which uses CDM-external data to shed light on the actual arrangements pertinent to each individual project. The key is 'observed organizational arrangements' as opposed to unverified 'claims'.

The study is based primarily on an original database of solar PV CDM projects (Table 2). The data collection takes point of departure in an existing database of all CDM projects (www.cdmpipeline.org by UNEP DTU Partnership) which contain some of the available information from each of the many official UNFCCC-approved project documents, excluding firm, sustainable development and technology transfer information. Accordingly, the new database of observed organizational arrangements developed for this study required the following research steps:

- First we consulted all the official project design documents and monitoring reports for each of the solar projects in all of the nine host countries in order to determine which specific solar PV equipment was used in each project. Projects documents are available from the UNFCCC website, www.cdm.unfccc.int.

⁵ This builds on a framework developed for a study of conventional technology transfer mechanisms in wind power projects in CDM (Lema and Lema, 2013). The wind-framework enabled an analysis of different mechanisms, but did not assess unconventional technology transfer. This study is a development of the existing framework in three ways. First, it extends the analysis to the solar sector. Secondly, it examines the degree to which unconventional mechanisms are used in solar CDM projects. Thirdly, as explained below, it adds a new conceptual variable in order to classify unconventional mechanisms.

⁶ The first three variables derive from Lema and Lema (2013), while the fourth has been added to account for unconventional mechanisms

Table 2
Overview of solar PV power CDM projects.

	Projects	Projects (%)	Mechanisms	Mechanism (%)	Capacity (MW)	Capacity (%)	Average capacity	Dominant technology
China	103	47.9%	160	49.1%	2767	66.9%	27	Polycrystalline
India	60	27.9%	73	22.4%	600	14.5%	10	Thin film
South Korea	25	11.6%	58	17.8%	182	4.4%	7	Monocrystalline
Thailand	21	9.8%	28	8.6%	392	9.5%	19	Polycrystalline, thin film
Peru	2	0.9%	2	0.6%	40	1.0%	20	Polycrystalline
UAE	1	0.5%	2	0.6%	10	0.2%	10	Monocrystalline, thin film
Saudi Arabia	1	0.5%	1	0.3%	11	0.3%	11	Thin film
Israel	1	0.5%	1	0.3%	105	2.5%	105	Monocrystalline
Dominican Republic	1	0.5%	1	0.3%	30	0.7%	30	Polycrystalline
Total	215	100%	326	100%	4135	100%	19	

Source: Authors' database based on a review of UNFCCC project documents.

Note: As of May 1st 2013 a total of 242 solar PV projects were UNFCCC-registered with project (credit) start dates up to June 1st 2013. Information was obtained for 215 projects. These projects covered 326 observed mechanisms.

technology into the host country and another local firm manufacturing its own technology modules locally, the project was categorized as both trade and local innovation. Of the 245 solar CDM PV projects in our database it was possible to obtain information for 215 projects. The 215 registered solar PV projects included 326 organizational arrangements. One organizational arrangement corresponds to one batch of modules produced by one specific firm.

To explain the findings of the 'observed organizational arrangements' methodology we explore the timing of establishment of organizational arrangements and whether countries with high degrees of diversity in their transfer activity also exhibit local existence of manufacturing and technological capabilities and an stimulating industrial policy environment. We focus on China, India and Thailand that all are non-OECD developing countries and the only solar PV CDM countries with projects involving three or more solar organizational arrangements. We cannot do justice to the history of PV industry development in these countries but pick the developments, policies and firms which we believe offer explanations to the empirical results. We will suggest that the observation of multiple organizational arrangements can be explained by the existence of pre-existing industrial and technological capabilities in the sector as judged from a review of actual CDM suppliers. This 'sequence methodology' test whether organizational arrangements (the date when the firm's technology venture started) began more or less simultaneous with the specific CDM project (the credit start date).

4. Explaining solar PV local innovation and technology transfer in CDM

This section first presents the empirical results of our study of organizational arrangements in solar PV CDM projects. By doing this we seek to examine the prevalence of 'unconventional' technology transfer. It also describes more broadly the key organizational arrangements in solar PV CDM projects and differences among CDM solar host countries with respect to the degree to which they host different types of organizational arrangements. We then seek to 'explain the findings' with the use of case studies of China, India and Thailand, focusing on why they exhibit diversity in organizational arrangements. These cases also allow us to examine the extent to which CDM projects spearhead new organizational arrangements in host countries.

4.1. Examining 'observed organizational arrangements'

In Table 3 we show the organizational arrangements identified in solar PV CDM projects. The first thing to note is that the share of organizational arrangements that involve some sort of 'technology transfer' (73%) is substantially higher than indicated by project participants' claims. Instead the share of projects that actually used imported technology (37%) corresponds to the share that claimed transfer (38%) in the project design documents. Projects participants seem to have equated 'technology transfer' with import. They have

not considered technology which is manufactured locally by firms that have used other types of conventional and unconventional technology transfer. In fact, many individual firms manufacture technology locally while engaging in unconventional transfer of technology through learning networks and cooperative endeavors in an underlying layer of the technology development process. There are thus big differences in the results unearthed by our observed organizational arrangements method compared to the 'claims' method that rely only on project design documents. This study reveals that 'technology transfer' is actually more widespread than usually observed, primarily because we are able to identify organizational arrangements that are 'unconventional' and not readily visible in CDM data. Altogether, about 60 different firms have supplied solar PV technology through CDM.

Table 3 shows the number and share of observed organizational arrangements distributed on types. The major organizational arrangements are trade, overseas R&D and local innovation while also joint ventures and joint R&D play a role. It appears that technology licensing and strategic acquisitions and alliances are negligible in CDM. But we know from other studies that latecomer PV firms have in fact used such strategies outside CDM (Lema and Lema, 2012). This data does therefore not imply that firms have not used these organizational arrangements earlier as a key element in their technological learning process. In many instances firms have earlier or as a part of their technology acquisition strategy also used licensing and acquired firms to obtain technology or vertically integrate the business. But they do not dominate in the technology strategies that underlie the CDM suppliers. However, the study of firm histories shows that several CDM suppliers have mixed conventional and unconventional organizational arrangements and in-house R&D. This is also aligned with the research that shows that latecomer solar PV firms are often strategically diversified (Mathews et al., 2011).

The data presented in Table 3 shows that unconventional transfer were used in 27% of projects. This provides nuance to the assertion that technology is only developed in and by developed country

Table 3
Technology mechanisms in solar PV CDM – an overview.

	Mechanisms	Share
Conventional	149	46%
Trade/import	119	37%
FDI	11	3%
Joint venture	18	6%
Licensing	1	0%
Unconventional	89	27%
Overseas R&D	62	19%
Joint R&D	24	7%
Strategic acquisitions and alliances	3	1%
Local innovation	88	27%
Total	326	100%

Source: Authors' database based on a review of UNFCCC project documents and sources as specified in Section 3.2.

Table 4
Technology mechanisms in solar PV CDM – by country.

Country	Import	FDI	Joint venture	License	Overseas R&D	Joint R&D	Strategic acquisitions and alliances	Local innovation	Total
China	1	9	13	1	56	22	1	57	160
India	47	–	5	–	6	–	2	13	73
South Korea	40	–	–	–	–	–	–	18	58
Thailand	24	2	–	–	–	2	–	–	28
Peru	2	–	–	–	–	–	–	–	2
UAE	2	–	–	–	–	–	–	–	2
Dom. Rep.	1	–	–	–	–	–	–	–	1
Israel	1	–	–	–	–	–	–	–	1
Saudi Arabia	1	–	–	–	–	–	–	–	1
Total	119	11	18	1	62	24	3	88	326

Source: Authors' database based on a review of UNFCCC project documents and sources as specified in Section 3.2.

organizations and 'transferred' to developing countries through trade in equipment, licensing of blueprints or other 'conventional' routes. On the contrary, it is clear that latecomer firms play a major role in solar PV technology. 27% of all solar PV CDM projects have been supplied by drawing on 'local innovation'. There is thus much more to the technology process underlying CDM than typical notions of transfer. In a significant share of cases, technology is 'acquired' rather than 'transferred'. What we mean by this is that local firms have often driven their own technology acquisitions, not just been 'passive' recipients. This is especially the case where latecomer firms have engaged in innovation in wholly owned subsidiaries overseas or jointly with foreign firms or organizations (at home or abroad). This has allowed firms to develop and refine technology with state-of-the-art skills and bring back results, know-how and know-why to manufacturing facilities at home. The next section will illustrate the processes in China, India and Thailand.

Thus far we have argued that this article portrays a more precise and detailed picture of technology transfer in CDM, and that we have provided data that suggests that technology transfer and local innovation is more diverse than is found in previous literature. Table 4 shows that this diversity – the existence of a broader variety of organizational arrangements than simply conventional technology transfer – is found in only a few, but major CDM countries. Only China, India and Thailand exhibit three or more different organizational arrangements. The distributions of arrangements on key aggregate categories for these countries are shown in Table 5.

To sum up, a broad variety of organizational arrangements have been observed. Conventional transfer – international trade, FDI, licensing, and joint ventures – accounted for less than half of CDM projects. Local innovation by latecomer firms and unconventional technology transfer both accounted for more than a quarter each. It was particularly noteworthy that overseas R&D and joint R&D by latecomer firms have become major sources of strategic technology acquisition. However, only a few countries have diversity in the types of organizational arrangements found in CDM. We now turn our attention to the broader industry development in solar PV in order to explain why these countries – China, India and Thailand – exhibit such organizational arrangements. Our aim in the following is to understand to what extent countries have a strong solar technological base which has been put to use in the supply of CDM projects.

Table 5
Shares of technology mechanism in case countries.

Country	Conventional		Unconventional		Local innovation		Total	
China	24	15%	79	49%	57	36%	160	100%
India	52	71%	8	11%	13	18%	73	100%
Thailand	26	93%	2	7%	0	0%	28	100%

Source: Authors' database based on a review of UNFCCC project documents and sources as specified in Section 3.2.

4.2. China

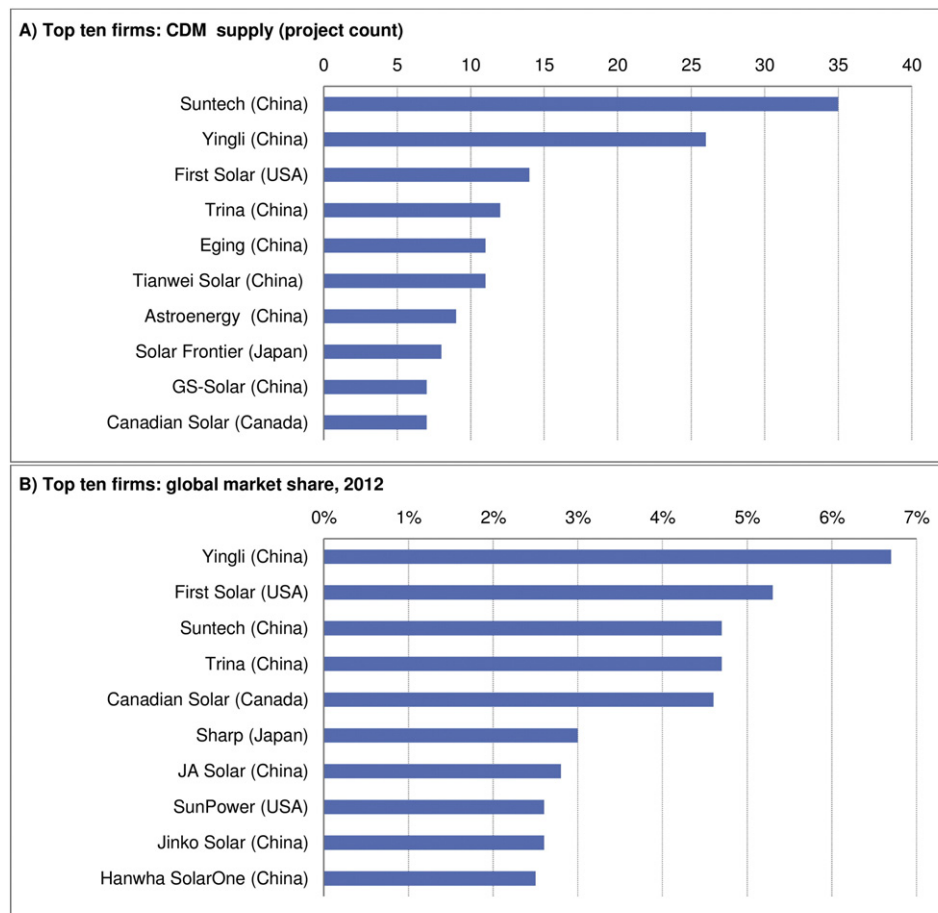
China is a unique case in solar PV CDM in several respects. To begin with, China has the largest share of local innovation and almost no imported equipment (Table 4). This should not give the wrong impression that China has no technology transfer. On the contrary, China is the most diversified host country in terms of organizational arrangements and is dominated by unconventional technology transfer.

A number of studies have documented the rapid technological development in China's solar PV industry (e.g. de la Tour et al., 2011; Fischer, 2012; Fu and Zhang, 2011; Grau et al., 2012). During the 2000s, the industry in China had a strong growth period. Chinese PV installations were quite slow due to inadequate policies to close the gap to much cheaper coal fired power. But with major global markets such as Germany, Japan, and the United States with strong financial deployment incentives, an export oriented Chinese strategy worked well. Later when markets such as Germany and the US plunged due to shrinking support programs and the economic crisis, China began developing both demand and supply side support (Grau et al., 2012; Zhao et al., 2013). Major demand side policies include the Golden Sun. program which provided 50–70% capital subsidies of solar projects, a national level feed-in tariff for large scale projects and regional level policies such as Jiangsu's feed-in tariff. Supply side policies included selective grants for basic research, cooperative R&D and demonstration, often contingent on local firms' ownership of proprietary technology and results. This encouraged local innovations and technology corporation with Chinese firms in the driver's seat. Other programs aimed at industry support and import tax exemptions for key materials and equipment. Moreover, low interest loans have been granted to several of the top Chinese manufacturers (Grau et al., 2012).⁷ The role of industrial policy in the sector is contentious and the US and EU has complained over unfair export subsidies.

While China was barely visible on the global solar PV map by the early 2000s, the country became the world's largest producer of solar PV cells in 2008. By 2011 China produced more than half the global annual output of both solar cells and modules. The Chinese industry has also moved into the upstream value chain segment and has become the leading manufacturer of the backbone material, polysilicon feedstock (IEA, 2012). Chinese firms are now among market leaders in the full production chain and it is not surprising that of the top-10 CDM suppliers, seven are Chinese, including the two leading firms (Fig. 2).

The two Chinese CDM leaders, Suntech and Yingli, are also among global leaders. Suntech tops the CDM market and exports more than 90% of its output. According to Suntech, its rise was not just about cheap Chinese labor but process and technological innovation to increase the photovoltaic efficiency level, with which Suntech has been

⁷ The global economic downturn since 2008 has had a major impact on several of the largest firms, including Suntech, striving with falling profit margins, debt and bankruptcy. This is reinforced by a great module capacity expansion in established firms and an expansion of new firms due to low barriers to entry.



Source: A) Authors' database based on a review of UNFCCC project documents and sources as specified in section 3.2; B) REN21, 2013.

Fig. 2. Top ten technology manufacturers in solar PV CDM and global non-CDM. Source: A) Authors' database based on a review of UNFCCC project documents and sources as specified in Section 3.2; B) REN21, 2013.

successful to achieve globally competitive cell efficiencies of 17–19% for polycrystalline and monocrystalline cells (Carus, 2011; Suntech, 2010).

Suntech is an example of a latecomer firm catching-up in the global PV market. On the one hand, Suntech is a case of local in-house R&D and local technology linkages. Suntech employs 450 persons in R&D across four continents and had R&D expenditures of about \$40 million in 2011. Suntech has issued 200 patents and further 300 pending applications globally, although the average quality of Chinese patents is uncertain. Local technology linkages are manifold with connections to at least five Chinese universities. On the other hand, Suntech has adopted a mixed transfer strategy of technology licensing, joint ventures, foreign acquisitions and especially overseas R&D in Australia and Germany. Examples of Suntech's ventures include a licensing agreement with German SolarWorld, foreign acquisitions and overseas R&D cooperation with Australian solar research institutions, University of New South Wales and Swinburne University of Technology (Suntech, 2010, 2012). Due to the very close relationship with overseas research institutions Suntech is categorized in this study as 'overseas R&D', although the firm's story is also much about local innovation and foreign acquisitions.

Established in 1998, global market leader, Yingli Solar, combines local and foreign organizational arrangements. Since the firm's weight is on overseas R&D it is categorized as such in this study. Yingli carries out in-house R&D in combination with especially overseas R&D in its PV testing lab in San Francisco, a R&D subsidiary in Spain and research and experimental development in Singapore. Moreover it has a major joint R&D project with the Energy Research Centre of The Netherlands and US solar firm, Amtech. Yingli have issued 700 patents (Yingli, 2012).

Table 4 shows that other organizational arrangements are also at play in China. This is especially local innovation companies which have mushroomed in China since the late 2000s causing overcapacity, which is aggravated by the global economic slump. These firms are rarely breakthrough innovators. However, China has for several decades had local solar PV technologies based on primarily own technology. One example is GS-Solar which has in-house R&D in several locations in China as well as technology cooperation with Chinese research institutions. The firm has developed and tested technology since 2003 and was officially established with production in 2008. GS-Solar has received support – as many other Chinese firms – from Chinese state research programs. The firm has issued more than 30 patents and uses about 5% of its output value in R&D. To be sure, local innovation firms often have various international technology linkages. First, a number of R&D employees have often studied or researched abroad. Secondly, an increasing number of global PV patents have expired and are freely available for use (Mallett et al., 2009).

The industry in China also hosts foreign solar firms. Global players such as DuPont Apollo and Canadian Solar have R&D and FDI in China with wholly owned production and research facilities. Korean Hanwha conglomerate acquired Chinese, Solarfun, to become Hanwha SolarOne. Australia-based BP Solar created the joint venture, BP SunOasis, with Chinese Xinjiang SunOasis (now withdrawn again). Table 6 provides an overview of key developments in China with regard to organizational arrangements.

The analysis above reveals two findings. First, a large number of Chinese solar manufacturers are globally competitive with the majority of

Table 6
Technology transfer and localized innovation in Solar PV CDM – China.

Technology transfer	Local innovation	
Conventional mechanisms	Unconventional mechanisms	In-house R&D and local technology linkages
Import: has played a limited role in general as the industry focuses on exports for global markets. No role in CDM.	Joint R&D: has played some role in the overall industry formation and major role in CDM.	In-house R&D: has been very important in almost all firms in general and in CDM, both as a primary strategy and in combination with technology transfer strategies.
FDI: has not been important to industry formation but is beginning to occur. Foreign companies play a small role in the CDM.	Strategic acquisitions and alliances: has become important to access foreign technology by some firms but no major role in CDM.	Local technology linkages: had a limited impact during take-off, but has now become important for several suppliers of CDM.
Joint ventures: are not significant in the industrial structure, but some notable firms are supplying CDM.	Overseas R&D: has played a major role in the industry.	
Licensing: plays a very small role as a primary strategy but has played some role in the take-off of some firms in combination with unconventional strategies.	Also plays a major role for some CDM suppliers due to cooperation with foreign research institutions.	

Source: Literature cited in Section 4.2, Lema and Lema (2012) and authors' database based on a review of UNFCCC project documents and sources as specified in Section 3.2.

their sales in Western non-CDM countries. CDM is not their key source of revenue or motive for strategic decisions on technology and production. For example, compared to Suntech's global annual shipments of almost 2000 MW in one year (2011), Suntech's CDM project sales of less than 500 MW over several years are not significant.

Secondly, the review of key firms in CDM indicates that they operate with various local and international technology decisions independently of CDM. This point can be examined in more detail by analyzing whether CDM transferred solar PV technology to the country for the first time and by assessing the time sequence in which the specific organizational arrangements (firms) observed in CDM projects was established in China (Table 7).

An example of the 'sequence' method is exemplified with the case of FDI: Independent of CDM, Canadian Solar established its first wholly owned subsidiary in China in 2001 while the first use of FDI in CDM was 10 years later. In other words, with a country focus technology transfer through FDI in CDM was not new to China. Moreover, the first firm using FDI in CDM (2011) was Hanwha SolarOne which one year earlier in 2010 acquired a Chinese firm that was established in 2004. With this project focus, there could be some role of CDM. However, comparing with another foreign firm which supplied a CDM project only somewhat later in early 2012, DuPont Apollo, its wholly owned subsidiary was established already in 2008. These findings shows first that FDI was not spearheaded by the CDM, and secondly, that foreign firms using CDM was investing several years earlier than its engagement in CDM, thus supporting our argument above that foreign firms had non-CDM motives. The same can be said about other organizational arrangements in China. If one looks exclusively at the two top-suppliers this finding is supported: Suntech was established in 2001 and its first overseas R&D venture, for instance, took off in 2002, well before CDM existed. Similarly, Yingli was established in 1998 but did not supply any CDM project until 2011.

As a general rule, the firms were established and their organizational arrangements implemented independent of and several years before their supply of CDM projects. Fig. 3 illustrates this time difference between non-CDM activities in the sector and CDM activity.

4.3. India

A largely similar solar technology history to that of China is present in India, although its global market share is much smaller. India has had a solar PV support program since the 1970s. To begin with, the industry was dominated by state owned enterprises undertaking R&D and manufacturing of solar modules (Bhargava, 2001). Indian firms and institutions engaged in 'local innovation' although the gap to the frontier of PV efficiency was wide (Kathuria, 2002). During the 1990s, a number of private firms entered the industry. The industry is primarily export oriented although feed-in tariffs and the recent Jawaharlal Nehru National Solar Energy Mission, with domestic installation targets of 20 GW in 2022, are setting the stage for stronger domestic demand. Among the important policies supporting Indian solar PV companies and attracting FDI to India is the local content requirements of the support program in which it is mandatory for cells and modules to be manufactured in India (Altenburg and Engelmeier, 2013; Sahoo and Shrimali, 2013).

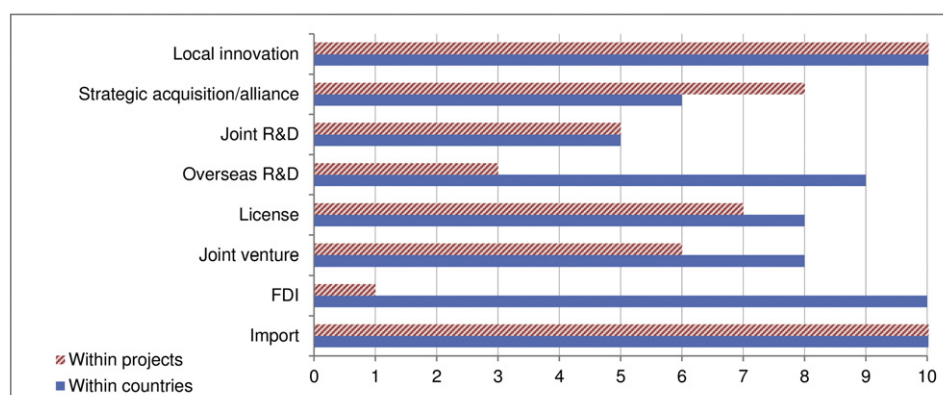
There are relatively few solar PV CDM projects in India. It is important to note that while showing some diversity in the use of organizational arrangements, the CDM data (Table 4) does not adequately reflect that a number of Indian solar PV manufacturers have used varying conventional and unconventional transfer including licensing and foreign expired patents, joint ventures, R&D cooperation, foreign acquisitions in addition to substantial in-house R&D (Fu and Zhang, 2011; Mallett et al., 2009). Table 8 indicates that the industry and indigenous technological capabilities have been developed largely independent of CDM.

Table 7
The sequence of technology mechanisms in China.

	First use of mechanism outside CDM	First use of mechanism in CDM	Time difference (years)	Establishment of the firm introducing the mechanism in CDM	Firm introducing the mechanism in CDM	Time difference (years)
Import	Within countries			Within projects		
FDI	Ca. 1960	2012	40–50	Ca. 1960*	Sunpower (2012)	40–50
Joint venture	2001 (Canadian Solar)	2011	10	2004/2010	Hanwha Solar One (2011)	1
License	2003 (Kyocera-Tianjin)	2011	8	2005	BP SunOasis (2011)	6
Overseas R&D	2004 (Suntech)	2012	8	2005	JA Solar (2012)	7
	2002 (Suntech)	2011	9	1977	Yunnan Tianda (2011)	34
				1998	Yingli (2011)	3
Joint R&D	2006 (Astroenergy)	2011	5	2006	Astroenergy (2011)	5
Strategic acquisitions and alliances	2006 (Suntech)	2012	6	2004	Hanergy (2012)	8
Local innovation	1977 (Yunnan Tianda)	2011	34	2000	Shanghai Solar Energy (2011)	11

Source: Annual reports and websites of cited firms; authors' database based on a review of UNFCCC project documents and sources as specified in Section 3.2.

* Not firm-specific, but same as first use of mechanism outside CDM.



Source: Annual reports and websites of cited firms; authors' database based on a review of UNFCCC project documents

and sources as specified in section 3.2

Fig. 3. Minimum time difference between non-CDM and CDM activity in China (years). Source: Annual reports and websites of cited firms; authors' database based on a review of UNFCCC project documents and sources as specified in Section 3.2

The organizational arrangements observed in CDM in India were not new to India when they were used in CDM (Table 9). More than 20 years passed before local technology firms began supplying CDM. Even if we look at the particular firms spearheading local innovation in CDM, Titan Energy, it was established and started manufacturing modules in the early 1990s before CDM was even established. Indian conglomerate TATA Power has since 1989 engaged in a joint venture with BP Solar. Regarding unconventional technology transfer, Moser Baer Solar was established in 2007 and has own manufacturing plants across the PV value chain, including solar cells. Moser Baer has used conventional technology transfer strategies such as a licensing agreement with Applied Materials and unconventional strategies such as overseas in-house R&D in Germany, strategic alliances and equity relations with foreign solar technology companies.

4.4. Thailand

In Thailand, a number of local technology module manufacturers have existed since the late 1980s, including the firm, Solartron (1986), and small scale imports into Thailand started in the 1990s. PV installations began to pick up in the mid-2000s where both local and foreign firms started manufacturing modules and some local firms diversified upstream into cell production (Sichanugrist, 2008). On the demand side, a feed-in tariff was in place by 2009 and goals are aiming at 3 GW of PV installations in 2020. Supply side policies have included eight years tax breaks, soft loans and investment grants, and an import tax exemption for machines and material which stimulate domestic manufacturing of solar PV cells and modules (IEA, 2012). In the rather fierce global competition, Thailand is steps away from the technological frontier. The industry is strongest in the relatively low-tech production

of modules based on imported cells although slowly increasing its capabilities in cell manufacturing (Sichanugrist, 2008).

The firms active in the Thai CDM market generally have established manufacturing and organizational arrangements some years prior to their CDM activities. In FDI, Japanese Sharp Solar has established a module assembly factory in Thailand. One of the local firms, Bangkok Solar, was established in 2003 as a manufacturer of thin film modules which later expanded into cells production. Bangkok Solar has had both in-house R&D and R&D cooperation agreements with Hungarian technology firm, BudaSolar, since 2008. There is no indication that CDM have played a major role in industry formation or the further development in the Thai solar industry (Table 10).

4.5. Other countries

The cases of China, India and Thailand showed first that they have considerable diversity in the use of organizational arrangements, including unconventional technology transfer and local innovation, and secondly, that this reflected the co-evolution of overall, non-CDM solar PV industry maturity and organizational arrangements. Thirdly, since the initiation of these diverse types of transfer preceded the supply of technology into CDM projects, the CDM has not had a spearheading role in the creation of the observed technological innovation capabilities. We now turn to a brief assessment of other countries with CDM solar projects.

As was shown in Table 4, a review of South Korean suppliers indicates that South Korea has both has local technology and imported solar PV modules for CDM projects. Imports independent of CDM have occurred since the early 1990s and local innovation activity at least since the early 2000s, several years ahead of the first CDM projects.

Table 8
Technology transfer and localized innovation in Solar PV CDM – India.

Technology transfer		Local innovation
Conventional mechanisms	Unconventional mechanisms	In-house R&D and local technology linkages
Import: has played a small role in general although a larger role in CDM. FDI: is not important in general or in CDM. Joint ventures: have played a major role in the industry's take-off and in CDM. Licensing: have played a major role in the industry's take-off, but a small and indirect role in CDM.	Joint R&D: has played a major role in maturing the industry, but a small and indirect role in CDM. Strategic acquisitions and alliances: has played some role in the industry, but a small and role in CDM. Overseas R&D: has played some role in the industry and a major role in CDM.	In-house R&D: is important in the industry, often in combination with technology transfer strategies. Local technology linkages: plays some role in the industry and some role in CDM.

Source: Literature cited in Section 4.3, Lema and Lema (2012) and authors' database based on a review of UNFCCC project documents and sources as specified in Section 3.2.

Table 9

The sequence of technology mechanisms in India.

	First use of mechanism outside CDM	First use of mechanism in CDM	Time difference (years)	Establishment of the firm introducing the mechanism in CDM	Firm introducing the mechanism in CDM	Time difference (years)
Import	Within countries			Within projects		
Joint venture	1970s	2011	30–40	1970s*	Mitsubishi and Kyocera Solar (2011)	30–40
Strategic acquisitions and alliances	1989 (Tata BP)	2012	22	1989	Tata BP (2012)	22
Overseas R&D	2006 (Moser Baer Solar)	2011	5	2006	Moser Baer Solar (2011)	5
Local innovation	2010 (Lanco)	2012	2	2010	Lanco (2012)	2
	1983 (BHEL)	2012	29	1991/1995	Titan Energy and Photon (2012)	22/17

Source: Annual reports and websites of cited firms; authors' database based on a review of UNFCCC project documents and sources as specified in Section 3.2.

* Not firm-specific, but same as first use of mechanism outside CDM.

Thus, South Korea appears similar to the countries mentioned above. A review of suppliers in all other countries show that these countries imported solar technology for its CDM installations. The solar PV CDM projects in Peru used imported modules from the Chinese firm, Suntech. Technology in the Israeli project that data could be obtained for was imported from China (Suntech, Canadian Solar) and the Philippines (by a wholly owned subsidiary of US firm, Sunpower). Projects in Saudi Arabia and Dominican Republic imported technology from Japan and China. The project in the UAE was supplied from China (Suntech) and Malaysia (First Solar). This latter example of First Solar provides some insight on the role of import in CDM. First, the most knowledge intensive technology transfer of First Solar was to open production lines in Malaysia. However, First Solar's choice of Malaysia as a manufacturing location in 2008 was not motivated by CDM (personal communication). First Solar's FDI in Malaysia needs to be explained in general internationalization processes of firms (UNCTAD, 2010). In this case, First Solar found Malaysia to be a skilled, low cost manufacturing hub suitable for export processing to third-markets. In addition, First Solar was granted full income tax exemption for the manufacture of thin film solar modules for 15 years. Moreover, according to First Solar its export of PV modules to the two projects in India and UAE was not motivated by CDM, but was motivated primarily as traditional sales business. This matters for how we understand the role of CDM in conventional technology transfer. CDM does provide financial incentives through sales of Certified Emissions Reduction credits which allow project developers to establish new projects and hence diffuse more technology. However, for the technology providers it matters less, if at all, whether the projects are CDM projects. The causal link between CDM and countries' use of one organizational arrangement over another is questionable.

What is notable is that these import countries have no solar PV industries themselves and host no firms among the 60 different technology suppliers that we have identified in this study. Accordingly import countries exhibit no local innovation and no technology transfer beyond imports that are combined with O&M training activities. Such training, of course, may deepen the flows of technology. However, evidence from project documentation suggests that accompanying training is often brief and concerned with operation. One import CDM project notes that, "technology transfer takes place through this kind of training. The one day session for the operation and management

has already been conducted by the experts from Suntech". Another import project notes: "The PV generation facilities used in this project were imported from Germany and the advanced foreign technologies will be transferred and spread in this field after construction of the project" and that the firm "who runs the facilities, can acquire more technological experiences and know-how for maintenance of the equipment."

As discussed in Section 2, this type of technology transfer can be clearly distinguished from unconventional technology transfer that requires prolonged and intense interaction and efforts by the recipient and typically provides more foundation for engaging creatively with the underlying technology.

5. Conclusions and implications

This paper started by outlining the twin aim of the CDM: (a) to reduce greenhouse gas emissions in the rich world and (b) to promote sustainable development in low and middle income countries. This paper adds to the literature which argues that the results concerning the second objective have been 'suboptimal' (Castle, 2012, p. 355). In this paper we have focused on technology transfer from advanced to developing economies within CDM as a means to stimulate sustainable development since technology transfer can contribute effectively to development of technological capabilities required to stimulate sustainable development (Ockwell et al., 2013).

We took point of departure in the literature on technological learning and innovation in developing countries (Bell and Figueiredo, 2012; Ernst and Kim, 2002; Fu et al., 2011) to examine the nature of technology transfer in CDM projects across countries. Our findings are relevant to the current debates over reform of the technology-related instruments of the global climate change regime as well as for the research which inform these debates. To bring this out, this section provides a summary of the key findings and outlines the key implications.

5.1. Main findings and insights

This paper has sought to add to the literature on CDM's contribution to development in climate-related industries and the role of technology transfer and local innovation (e.g. de Coninck et al.,

Table 10

The sequence of technology mechanisms in Thailand.

	First use of mechanism outside CDM	First use of mechanism in CDM	Time difference (years)	Establishment of the firm introducing the mechanism in CDM	Firm introducing the mechanism in CDM	Time difference (years)
Import	Within countries			Within projects		
FDI	Ca. 1990	2011	21	Ca. 1990*	Powercom (2011)	21
Joint R&D	2005 (Sharp)	2011	6	2005	Sharp (2011)	6
	2003/2008 (Bangkok Solar)	2012	9/4	2003/2008	Bangkok Solar (2012)	9/4

Source: Annual reports and websites of cited firms; authors' database based on a review of UNFCCC project documents and sources as specified in Section 3.2.

* Not firm-specific, but same as first use of mechanism outside CDM.

2007; Dechezlepretre et al., 2009; Haščič and Johnstone, 2011). The valued added of this paper is two-fold.

First, we found that technology transfer in CDM solar projects is highly diverse across countries and that a range of rather sophisticated 'unconventional' organizational arrangements buttress a significant share of projects. However, these projects are concentrated in upper middle income countries. The important point is that organizational arrangements for technological learning utilized in CDM have co-evolved with overall capability building. The existing debates already take into account that countries do not stand still. With reference to countries such as China and India, the High-Level Panel on the CDM Policy Dialogue notes that increasing levels of technological capabilities mean that 'technology transfer, particularly for large-scale renewable power generation, is less and less necessary over time' (CDM Policy Dialogue, 2013, p. 46).⁸ It is argued that technology transfer increases the capabilities of recipient countries and these capabilities can substitute further transfer. Our findings complicate this argument. Rather than becoming less important, the nature of technology transfer changes over time. As will be discussed further below, this is important because it underlines the need to differentiate between countries at different levels of development.

Second, the study raises questions about the role of CDM in kick-starting the observed deepening of the technological learning. Technology transfer is important because increasingly advanced organizational arrangements contribute to capabilities with which host countries can manage sustainable development. But the evidence suggests that 'unconventional technology transfers' in China, India and Thailand were initiated prior to their use in CDM projects. The study suggested that the organizational arrangements observed in CDM were mainly a function of practices that already existed in host countries. Especially China, but also India and Thailand (along with South Korea), stand out from other host countries because they already had reached a certain level of industrial development with local and foreign solar PV firms. This study indicates that policy environments and independent firm strategies have been most important for developing the capabilities relevant to climate change mitigation. Our analysis indicate that policies such as technology push and market pull helped to build firm level capabilities and that firm strategies sought to upgrade capabilities further through global and local organizational arrangements suited for increased technological learning. In other words, the study raises questions about the overall contribution of CDM to the development of technological capabilities as compared to processes of technological learning occurring independently of CDM.

In sum, the conclusions of this paper imply that the literature on CDM should examine the effect of CDM on technology transfer and development in low-carbon actors and sectors in recipient countries. In particular, it should address the problem of attribution so that the isolated effect of CDM is analytically disentangled and compared with technological learning which has occurred independently of CDM. Distinguishing in this way between technology transfer and learning processes associated with CDM and processes occurring independently of CDM, the literature should pay particular attention to the diversity and dynamism of the organizational arrangements involved.

The conclusions of the paper are not only relevant for researchers. On the contrary, they raise important questions for policy makers interested in the interplay between climate policy, sustainable development and technological capability building in renewable energy technologies. The final part of the article seeks to bring out the most important implications.

⁸ Similarly the UNFCCC notes that "the frequency of technology transfer declines over time as local expertise related to the relevant technologies grows" (UNFCCC, 2012, p. 38) and argues that "the need for technology transfer falls as local sources of knowledge and equipment become more available and expertise in the technologies grows." (UNFCCC, 2012, p. 31).

5.2. Implications for climate regime mark II

'Climate Regime Mark I' – in which the CDM was an important element – is coming to an end. An extension of Climate Regime Mark I was secured with a 'second commitment period' of the Kyoto Protocol and the CDM will continue in this extension phase (2013–2020). However, at the time of writing, the Mechanism is challenged by the near collapse of effective demand for purchasing certified emission reductions which has put CDM to a virtual standstill. Moreover, it is uncertain what role CDM (or other offset mechanisms) will play – if any – in 'Climate Regime Mark II', currently envisaged to be agreed upon in Paris in 2015, alongside nationally determined contributions, the Green Climate Fund, the Climate Technology Centre and Network and so forth. Regardless of its future, it is important to keep lessons learned in mind when designing the new global regime. Four issues arising from this study seem particularly important for Climate Regime Mark II deliberations.

- (A) There is a clear need to differentiate between different developing countries in terms of their level of development. The experience from CDM suggest that the old distinction between Annex 1 and Non-Annex 1 countries is no longer tenable. The capabilities and finance power in some emerging economies is reaching a level in which it is increasingly questionable whether CDM projects are truly additional to what these would do by themselves in the absence of CDM. If this is the case, CDM projects in these countries do not contribute directly to global mitigation or indirectly to deepening of relevant capabilities. The high share of projects in emerging economies may be crowding out potential projects in poorer developing countries and a CDM-like instrument could become one mechanism in the Climate Regime Mark II which is focused specifically on low and middle income countries.⁹ This is not to say that there is no need to provide incentives and mechanisms for green transformation in upper middle income countries. However, mechanisms devised for the latter may focus more on guarantees and other types of support for raising commercial finance capital and on incentives to push the innovativeness of new projects, not least through local and global technology linkages.
- (B) Initiatives and mechanisms within the new regime should specify carefully what climate-relevant technological development and learning is and how mechanisms and initiatives should contribute to it. Technology transfer outcomes have been unspecified and vague within CDM, such as in the formulation of project design documents. The outcomes need to be specified clearly and emphasize their contribution in building local capabilities suited to national technology needs.
- (C) Policy makers concerned with global climate technology agenda may use the insights of this article to reflect on the fact that many BASIC countries (Brazil, South Africa, India and China) now have capability levels that allow them to engage proactively in climate-relevant innovation and cooperation. The models and practices that have grown out of BASIC countries may also be more relevant to low income countries than those from Annex-1 countries and hence there may be need to pay particular attention to South–South technology transfer.
- (D) All of the points above align with the argument that the climate and development agendas should be brought closer together by a process of policy harmonization. In this respect it is important to make sure that that technology and learning becomes mainstreamed across the various policies, programs and funds in Climate Regime Mark II. Technology transfer and learning is

⁹ From 2013 the European Union only allows usage of CDM credits from Least Developed Countries.

not a requirements in CDM, it is merely an outcome to be hoped for. But low carbon learning and development should not be a by-product of initiatives in Climate Regime Mark II; it should be one of the core objectives. This obviously makes mitigation efforts more costly in the short run, but the policy community needs to develop a dynamic perspective. Increased technological capability in the low carbon field is likely to spur enhanced mitigation action in the long run. A stronger focus on technological learning could assist low and middle income developing countries to enter a virtuous cycle in which upgrading of capabilities increases long run climate change mitigation efforts beyond individual projects and programs.

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